electric signal and thus may increase an information transfer speed. The control light may be an optical pump pulse.

[0093] In a case in which a graphene device **100** according to an exemplary embodiment is used as a high speed optical modulator, the substrate **10** may include a material having a band gap greater than the energy of control light. The substrate **10** may be an insulating substrate, and a sapphire substrate.

[0094] For example, in a case in which the substrate **10** is a silicon substrate, since silicon is a semiconductor material having an indirect bandgap, an optical energy emitting speed of an electron inside the silicon is about 1 μs. Since the optical energy emitting speed of the silicon is much slower than the optical energy emitting speed of graphene, the slow modulation speed of silicon has a greater influence on the light modulation speed than the fast modulation speed of graphene. Therefore, a graphene device **100** according to an exemplary embodiment, may be formed on an insulating material having a high energy bandgap.

[0095] FIG. **11** is a view illustrating a graphene device **100** that may modulate light by using control light according to an exemplary embodiment. Referring to FIG. **11**, when first light Li, which is a modulation object, is incident, second light Lr, which is light of a specific wavelength from among the first light Li, may be reflected under control of a gate voltage. The specific wavelength of the reflected light may change depending on the magnitude of the gate voltage.

[0096] Also, third light Lc may be incident on the graphene device **100** of FIG. **11**. The third light Lc may be a pulse type as control light. The third light Lc may be an optical-pump pulse. Since the optical energy emitting speed of graphene is about 1 ps, the third light Lc may be a femto-second optical pulse.

[0097] Light excitation of an electron inside graphene by an optical pump raises the temperature of the graphene, and increases the resistance of the graphene. Light emission of an electron inside graphene by an optical pump lowers the temperature of the graphene, and reduces a resistance of the graphene. Since the temperature change of the graphene is very fast, several pico seconds, the graphene device **100** according to an exemplary embodiment may modulate incident light by using control light.

[0098] Furthermore, as understood by a person of ordinary skill in the art, a graphene device **100** according to an exemplary embodiment may adjust the wavelength band of the second light depending on the gate voltage, and reflect the second light in any of various wavelength bands. Therefore, information may be provided to various kinds of apparatuses by using one graphene device **100**. FIGS. **12**A and **12**B are views for explaining waves reflected by the graphene device **100** depending on a gate voltage according to an exemplary embodiment. As illustrated in FIGS. **12**A and **12**B, when control light is used, the intensity of the second light may change depending on the pump-on or pump-off state of the control light at a switching speed of several pico seconds. Also, the wavelength of the second light may be adjusted depending on the magnitude of the gate voltage. To make the wavelength of the second light illustrated in FIG. **12**B greater than the wavelength of the second light illustrated in FIG. **12**A, the magnitude of the negative gate voltage may be increased.

[0099] As described above, in a case in which the graphene device **100** is used as a modulator that reflects specific light, the drain electrode **62** and the source electrode **64** of the graphene device **100** illustrated in FIG. **1** are not essential components. Therefore, the drain electrode **62** and the source electrode **64** may be omitted from the graphene device **100** operating as a modulator.

[0100] The graphene device **100** according to an exemplary embodiment may be used as a switching device. For example, a current flow between the drain electrode **62** and the source electrode **64** may be controlled by adjusting the magnitude of a voltage of the gate electrode **66** with a predetermined voltage applied to the drain electrode **62** and the source electrode **64**. FIGS. **13** to **16**B are views for explaining a method of manufacturing a graphene device according to an exemplary embodiment.

[0101] As illustrated in FIG. **13**, the plurality of meta atoms **20** may be patterned on the substrate **10**. The plurality of meta atoms **20** may be spaced apart from each other and arranged in a lattice configuration. At least one of the plurality of meta atoms **20** may have a radial shape. The plurality of meta atoms **20** may be formed on the substrate **10** by using an electron beam lithography method. The meta atom may include metal.

[0102] Also, as illustrated in FIG. **14**, the graphene layer **30** that covers the plurality of meta atoms **20** may be formed on the substrate **10**. The graphene layer **30** may be synthesized by using chemical vapor deposition (CVD), and the synthesized graphene layer **30** may be transferred.

[0103] A process of synthesizing graphene by using the CVD is described below.

[0104] First, a silicon wafer having a silicon oxide layer (SiO_2) (alternately, various insulating substrates may be used) is prepared. Subsequently, a metal catalyst layer is formed by depositing metal catalysts, such as Ni, Cu, Al, and Fe, on the prepared silicon layer (SiO_2) by using a sputtering unit, an e-beam evaporator, etc.

[0105] Next, the silicon wafer on which the metal catalyst layer has been formed, and a gas including carbon (CH_4, C_2H_2, C_2H_4, CO, etc.) are inserted into a reactor for thermal chemical vapor deposition or inductive coupled plasma chemical vapor deposition (ICP-CVD) and are heated to allow carbon to be absorbed into the metal catalyst layer. Subsequently, graphene is grown by rapidly performing cooling, separating carbon from the metal catalyst layer, and crystallizing the carbon.

[0106] Alternately, the graphene layer **30** may be formed by using a micro-mechanical method, CVD, etc. The micro-mechanical method pastes an adhesive tape on a graphite test piece, peels off the adhesive tape, and thereby obtains graphene on the surface of the adhesive tape separated from the graphite. According to a SiC crystalline pyrolysis method, when a single crystal of SiC is heated, the SiC on the surface decomposes, the Si is removed, and graphene is generated by the remaining carbon component. The forming of the graphene layer **30** is not limited to one of the above-described graphene synthesis methods, and the graphene layer **30** may be formed by using any of various other methods.

[0107] As illustrated in FIGS. **15**A and **15**B, the drain electrode **62**, the source electrode **64**, and the gate electrode **66** may be formed on the substrate **10**. The drain electrode **62**, the source electrode **64**, and the gate electrode **66** may be spaced apart from each other. For example, the drain electrode **62**, the source electrode **64**, and the gate electrode **66** may each contact the substrate **10**. The drain electrode **62** and the source electrode **64** may be separated from each